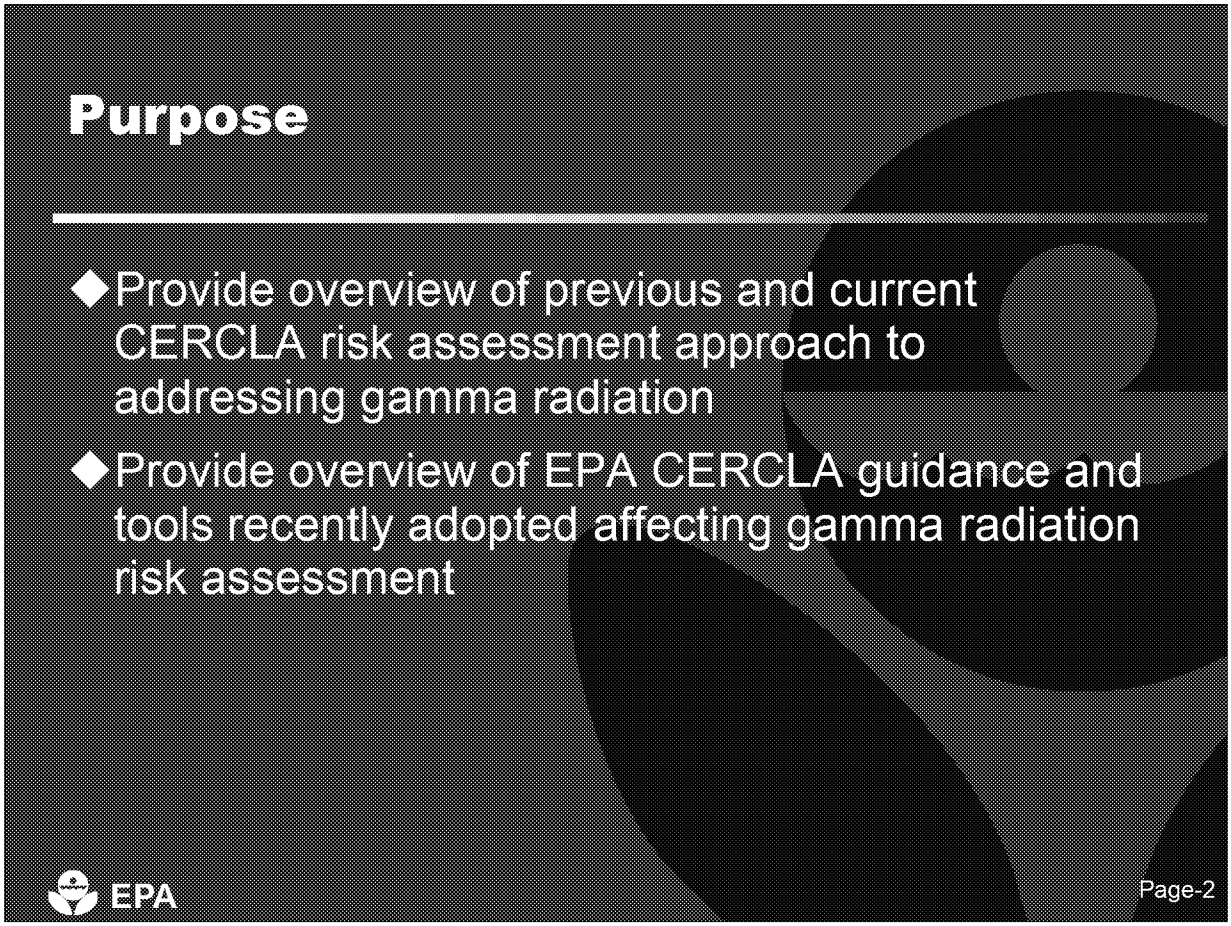
Evolving Adjustments to External (Gamma) Slope Factors for CERCLA Radiation Risk Assessments

Stuart Walker
U.S. Environmental Protection Agency
Office of Superfund Remediation
and Technology Innovation (OSRTI)
Science Policy Branch

Presentation to
2011 American Nuclear Society Winter Meeting
and Nuclear Technology Expo
in Washington, DC on Tuesday November, 2011

EPA



The focus of this presentation is on how radiation is addressed by the Superfund program, consistent with CERCLA and the NCP. The presentation will also provide a brief overview of guidance documents that were developed to address policy issues (such as interpretation of particular ARARs) and electronic tools for addressing radioactively contaminated sites.

CERCLA Risk and Dose Calculators

Human Health - Radiological

Cancer risk (1×10^{-6})

- PRG (soil, water and air) 2002
- BPRG (inside buildings) 2007
- SPRG (outside surfaces) 2009

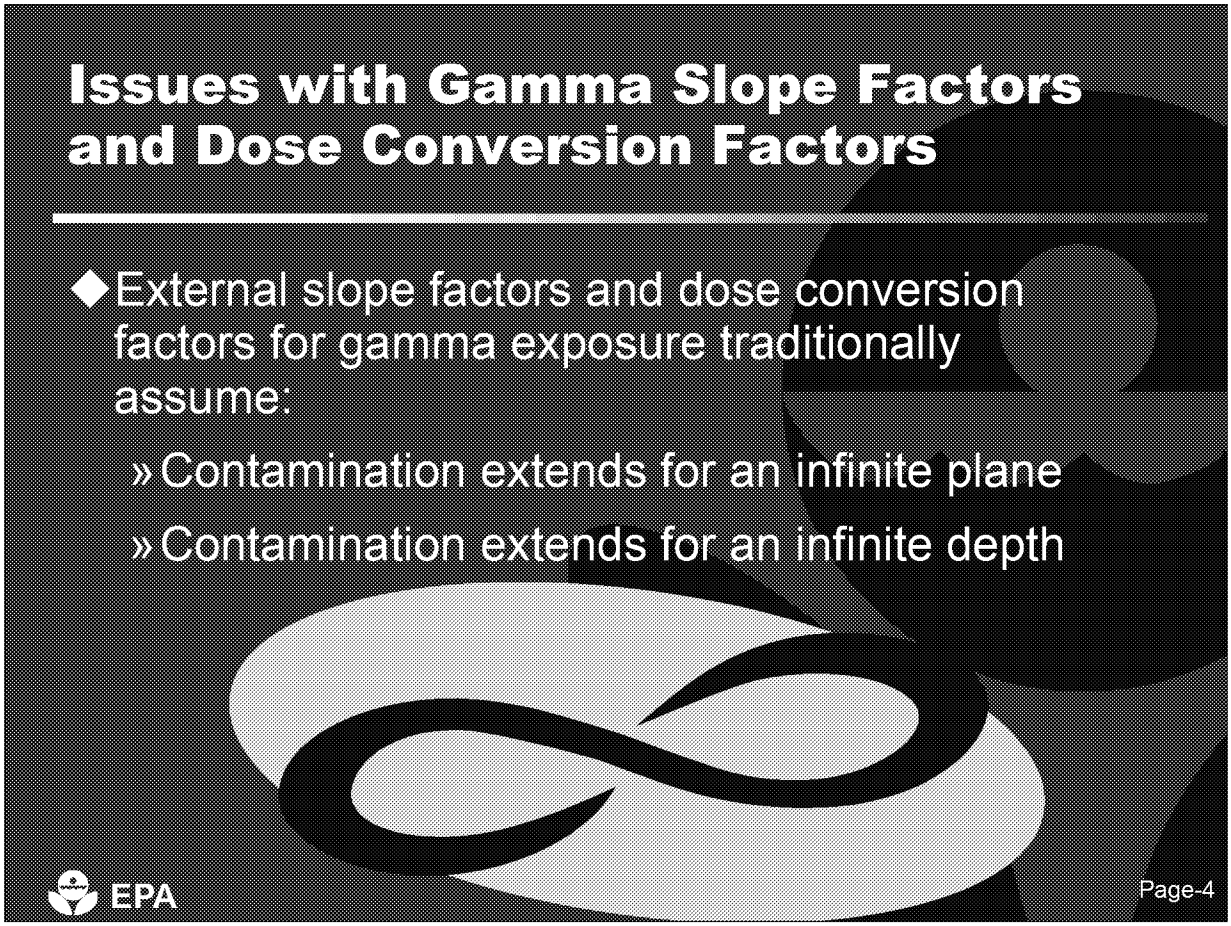
Dose (millirem per year)

- DCC (soil, water and air) 2004
- BDCC (inside buildings) 2009
- SDCC (outside surfaces) 2009

Human Health - Chemical

- RSL (soil, water, and air) 2008

EPA



At Superfund radiation sites, EPA generally evaluates potential human health risks based on the radiotoxicity (i.e., the adverse health effects caused by ionizing radiation), rather than on the chemical toxicity, of each radionuclide present. Uranium, in soluble form, is a kidney toxin at mass concentrations slightly above background levels, and is the only radionuclide for which the chemical toxicity has been identified to be comparable to or greater than the radiotoxicity, and for which a reference dose (RfD) has been established to evaluate chemical toxicity. For radioisotopes of uranium, both effects (radiogenic cancer risk and chemical toxicity) should be considered.

Risks from radionuclide exposures should be estimated in a manner analogous to that used for chemical contaminants. That is, the estimates of intakes by inhalation and ingestion and the external exposure over the period of exposure estimated for the land use (e.g., 30 years residential, 25 years commercial/industrial) from the exposure assessment should be coupled with the appropriate slope factors for each radionuclide and exposure pathway. Only excess cancer risk should be considered for most radionuclides (except for uranium). The total incremental lifetime cancer risk attributed to radiation exposure is estimated as the sum of the risks from all radionuclides in all exposure pathways.

Excess cancer risk from both radionuclides and chemical carcinogens should be summed to provide an estimate of the combined risk presented by all carcinogenic contaminants. An exception would be cases in which a person reasonably cannot be exposed to both chemical and radiological carcinogens. Similarly, the chemical toxicity from uranium should be combined with that of other site-related contaminants.

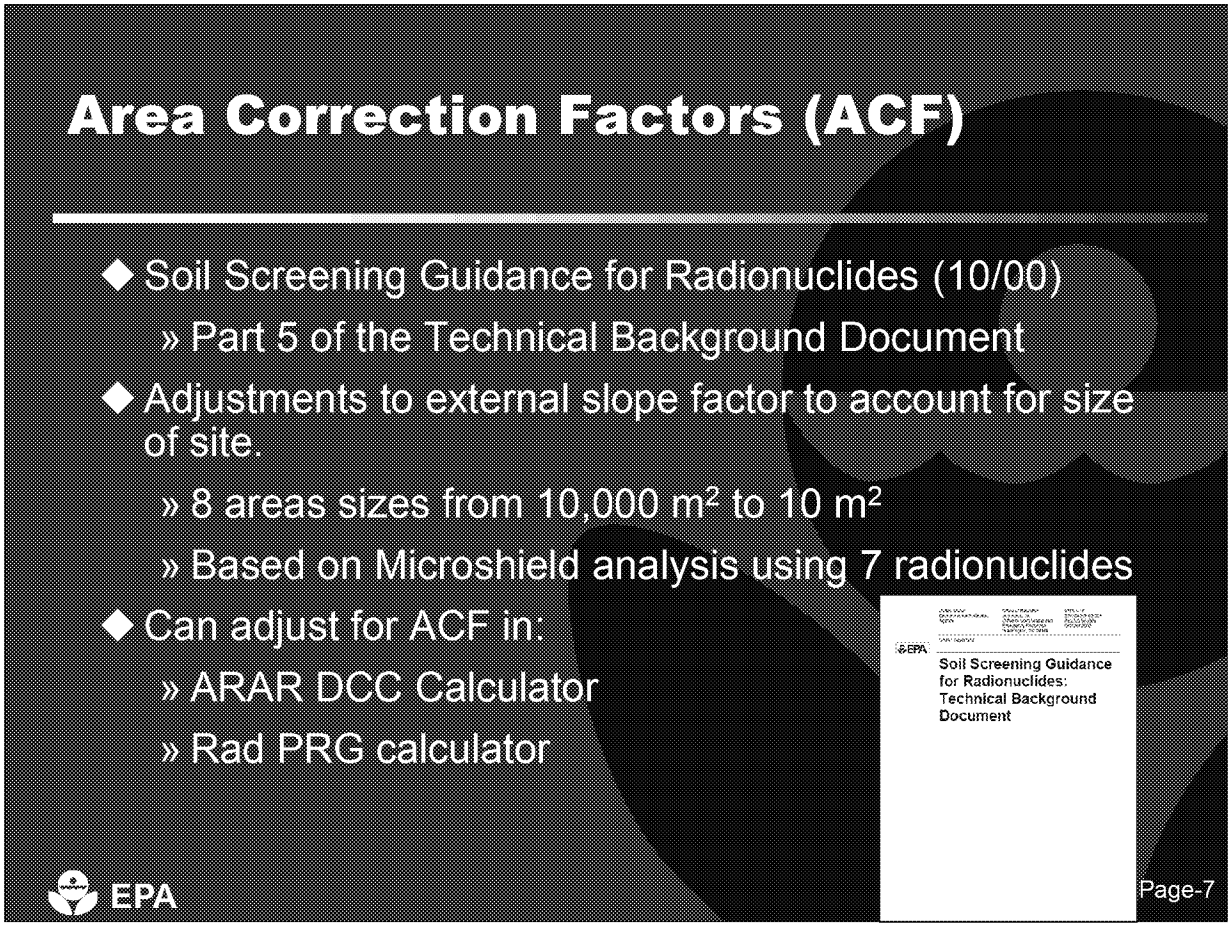
Radiation risk assessments include most of the same exposures that are assessed for exposure to chemicals (such as soil ingestion, fugitive dust inhalation, and drinking water). Risk assessments for radiation also include exposure to external gamma radiation, radon, and consumption of produce (e.g., fruit, vegetables, milk, and beef) grown at the site. Radiation risk assessments do not assess dermal exposure since this exposure pathway is considered insignificant in relation to other exposures that are assessed.

Problem with Infinity

- Assumption of infinite contamination
  - » May lead to overestimation of risk
    - —Contamination does not extend forever over the horizon or down to China
    - —At some point large enough radiation field does mimic infinity

1.
Surface Area Fixes

EPA



These guidance documents provide information on soil screening for radionuclides when setting remediation goals at CERCLA sites with radioactive contamination.

The guidance is intended to be used early in the CERCLA process to screen out areas of sites, exposure pathways, or radionuclides of concern from further consideration, assuming certain conditions are present, or to determine that further study is warranted at a site. Its use may significantly reduce the time it takes to complete soil investigations and cleanup actions at some sites, as well as improve the consistency of these actions across the nation. The guidance was written to enhance the efficiency of remedial investigation/feasibility study (RI/FS) work at NPL sites but may be utilized at corrective action sites or voluntary cleanup sites where site conditions are similar.

The guidance includes procedures for conducting site surveys.

The Technical Background Document (TBD) contains an evaluation of five detailed soil to groundwater vadose zone models (HYDRUS, MULTIMED-DP, FECTUZ, CHAIN, CHAIN 2D) for more complete site conditions. The report Simulating Radionuclide Fate and Transport in the Unsaturated Zone: Evaluation and Sensitivity Analyses of Select Computer Models provides a more detailed technical analysis of these five models. This report supports the information provided in the TSD on determining the general applicability of the models to subsurface conditions, and an assessment of each model's potential applicability to the soil screening process. The report is available:
as one file
http://www.epa.gov/ada/download/reports/600R02082/600R02082-full.pdf
or broken into sections
http://www.epa.gov/ada/download/reports/600R02082/600R02082.pdf

ACF in PRG/DCC calculators

- Recommendation for ACF with 8 site sizes in Rad SSG TBD

Table 5.1 Recommended Area Correction Factors as Function of Source Area

Source Area (m^2)	ACF
10,000	1.00
5,000	0.94
2,000	0.90
1,000	0.88
500	0.86
100	0.75
50	0.66
10	0.40

EPA

ACF 7 analyzed radionuclides

- Only if you had one of the 7 radionuclides used for analysis could you use radionuclide-specific ACF

Table 5.2 Area Correction Factors as Function of Source Area for Selected Radionuclides Calculated Using MicroShield

Source Area (m^2)	^{241}Am	^{60}Co	^{137}Cs	^{239}Pu	$^{226}Ra+D$	^{232}Th	$^{238}U+D$
10,000	1.00	1.00	1.00	1.00	1.00	1.00	1.00
5,000	0.93	0.95	0.95	0.94	0.95	0.94	0.94
2,000	0.89	0.92	0.92	0.90	0.92	0.89	0.91
1,000	0.87	0.90	0.90	0.89	0.90	0.88	0.89
500	0.85	0.87	0.87	0.86	0.87	0.86	0.86
100	0.76	0.75	0.76	0.78	0.75	0.77	0.76
50	0.69	0.66	0.67	0.71	0.66	0.70	0.68
10	0.44	0.38	0.39	0.45	0.38	0.44	0.41

EPA

This electronic calculator provides information on establishing Preliminary Remediation Goals (PRGs) for radionuclides at CERCLA sites with radioactive contamination.

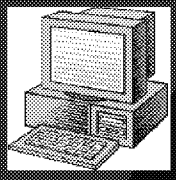
PRGs for CERCLA are:
Concentrations based on ARARs
Risk-based concentrations, derived from equations combining standardized exposure assumptions with EPA toxicity data.

The electronic calculator presents risk-based standardized exposure parameters and equations that should be used for calculating radionuclide PRGs for residential, commercial/industrial, and agricultural land use exposures, tap water and fish ingestion exposures. The calculator also presents PRGs to protect groundwater which are determined by calculating the concentration of radioactively contaminated soil leaching from soil to groundwater that will meet MCLs or risk-based concentrations.

The calculator may be found at: http://epa-prgs.ornl.gov/radionuclides/

Building PRG (BPRG) Calculator

- Establish 1 x 10^{-6} risk based PRGs for ***inside*** radioactively contaminated buildings
- Equations and parameters are derived from latest EPA chemical methodology (e.g., assessment at World Trade Center)
  - » Adjusted to account for technical differences posed by radiation



EPA

Page-10

The NCP sets forth nine criteria for selecting Superfund remedial actions. These evaluation criteria are the standards by which all remedial alternatives are assessed and are the basis of the remedy selection process. The criteria can be separated into three levels: threshold, balancing, and modifying. The first two criteria are known as "threshold" criteria. While every Superfund site is unique (whereby cleanups must be tailored to the specific needs of each site), the threshold requirements must be met at every site:

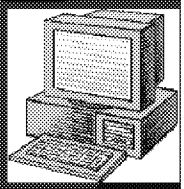
CERCLA requires that all remedial actions at Superfund sites must be protective of human health and the environment. Therefore, cleanup actions are developed with a strong preference for remedies that are highly reliable, provide long-term protection, and provide treatment of the principle threat to permanently and significantly reduce the volume, toxicity, or mobility of the contamination.
CERCLA specifically requires Superfund actions to attain or waive the standards and requirements found in other state and federal environmental laws and regulations. This mandate is known as compliance with "applicable or relevant and appropriate requirements" or ARARs.□□Site cleanups should protect groundwaters that are current or potential sources of drinking water to drinking water standards whenever practicable. The standards include federal Maximum Contaminant Levels (MCL) promulgated under the Safe Drinking Water Act and more stringent state drinking water standards.

BPRG Exposure scenarios

- BPRG calculator includes 2 land use scenarios
  - Residential
  - Indoor worker
- Both land uses include 3 exposure routes
  - Settled dust
  - Ambient air
  - **Direct external exposure**
    - **Surface**
    - **Volumetric**

Building Dose Cleanup Concentrations (BDCC) ARAR Dose Calculator

- BDCC Purpose: to establish BCCs for Inside Buildings for single dose limit ARARs (# mrem/yr)
- BDCC includes 2 land use scenarios (Residential, Indoor Worker)
- 2 land uses include 3 exposure routes (Settled dust, Fixed Direct External 3-D, Ambient Air)
- Equations similar to those used for BPRG calculator, except dose conversion factors used instead of slope factors



EPA

Page-12

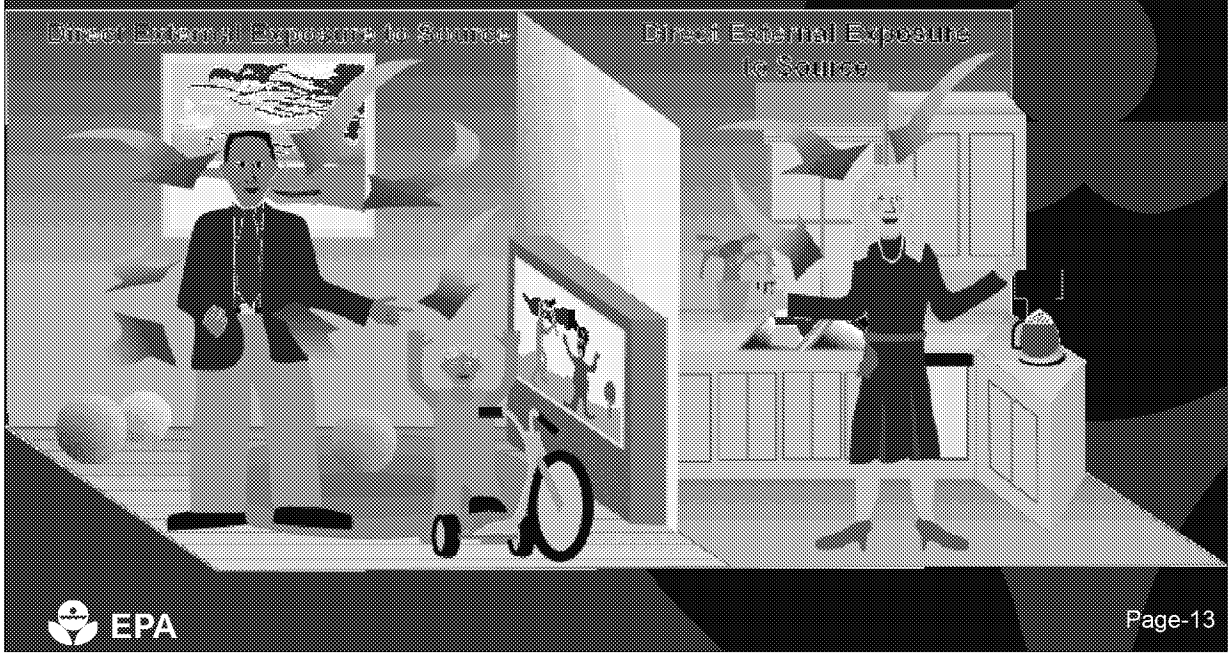
An approach similar to that taken for calculation of PRGs may also be used to calculate soil "compliance concentrations" based upon various methods of dose calculation.

A set of simple equations for target dose rate (e.g., either critical organ dose or single limits), radionuclide dose conversion factor (DCF), and intake/exposure parameters will be presented for use in calculating soil cleanup concentrations. These equations will be identical to those in the PRG for Radionuclides, except that the target dose rate (ARAR based) will be substituted for the target cancer risk (1 x 10-6), the period of exposure is one year to indicate year of peak dose, and a DCF will be used in place of the slope factor.

Please note that the target dose rate is generally a cleanup level when a dose standard is an ARAR (other than single dose limits greater than 15 mrem/yr such as NRC's 25/100 mrem/yr decommissioning rule), while the target risk number of 10-6 is a preliminary number.

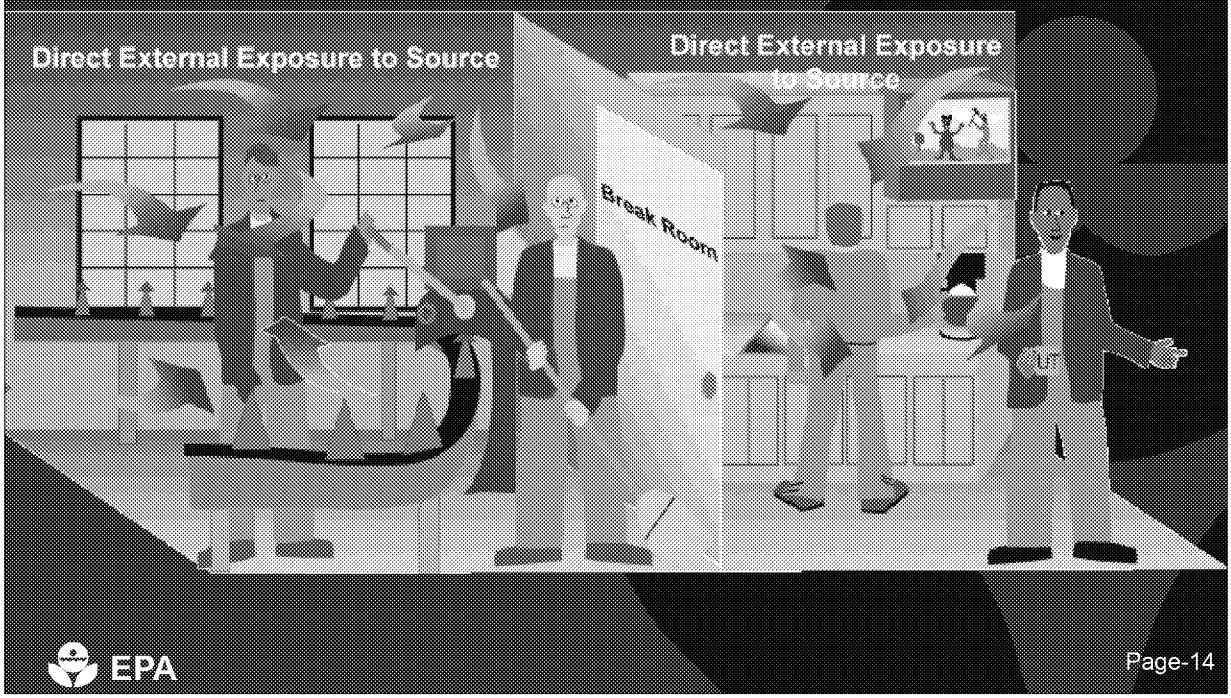
Site decision-makers should choose the DCFs (ICRP 2, 30, or 60) required by the ARAR. Note that this calculator does not address ICRP 2. If DCFs are not specified within the regulation (for example, specifically required for compliance within the Code of Federal Regulations for a federal standard that is being complied with as an ARAR), then site decision-makers should generally use ICRP 2 DCFs for whole body and critical organ dose limits (e.g., 25/75/25 and 25/75 mrem/yr dose limits), and generally use ICRP 60 DCFs for single limit standards (e.g., 10 mrem/yr).

Direct External - Residential



EPA

Direct External - Workers



EPA

BPRG/BDCC Positioning Factors: Room Sizes

- 5 Room sizes
  - 10 x 10 x 10 feet
  - 50 x 50 x 10 feet
  - 100 x 100 x 10 feet
  - 200 x 200 x 20 feet
  - 400 x 400 x 40 feet

BPRG/BDCC Positioning Factors: Receptor Location

- 4 Receptor Locations in each of the 5 room sizes
  - Averaged across all room positions
  - Center of room
  - Corner of room
  - Center of wall

Table 1. Ratio of the dose rate at various locations in the 10 x 10 x 10 ft room to that for an infinite plane source.

	Ratio			
Nuclide	Average	Center	Mid Wall	Corner
H-3	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Be-7	7.64E-01	6.21E-01	9.51E-01	1.05E+00
Be-10	8.40E-01	6.84E-01	1.05E+00	1.16E+00
C-11	7.59E-01	6.17E-01	9.45E-01	1.04E+00

EPA

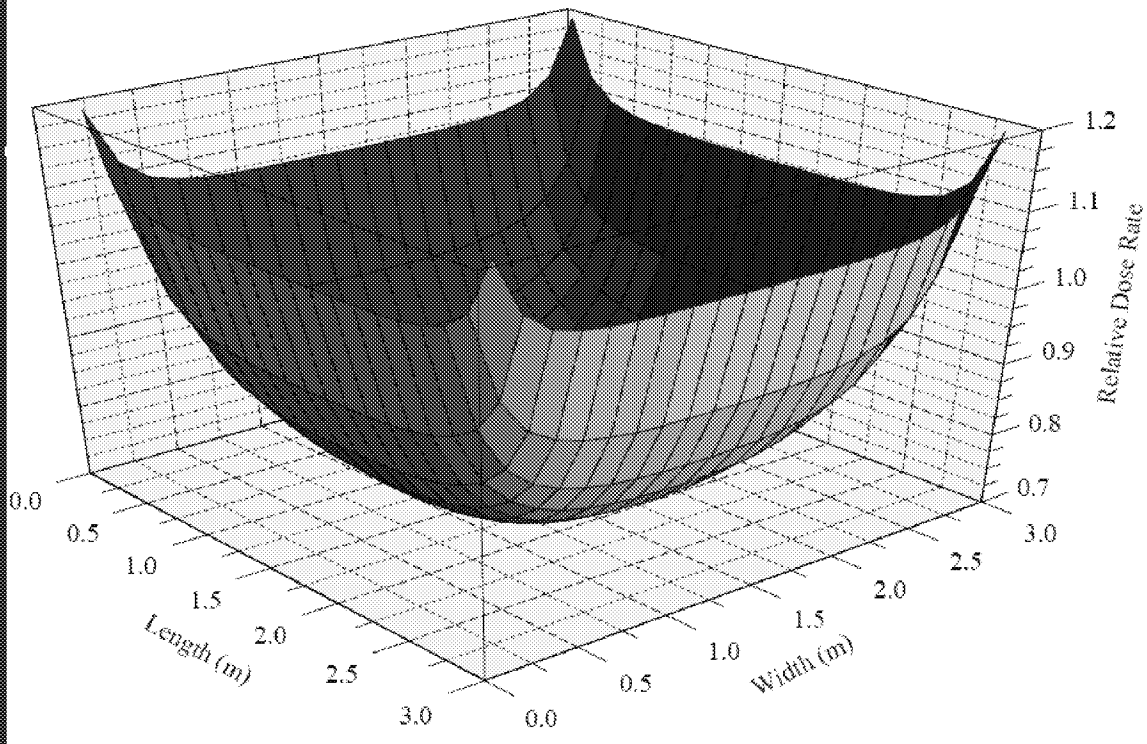


Fig. 1. Photon dose rate inside small room (10 x 10 x10 ft) for a 100 keV source.

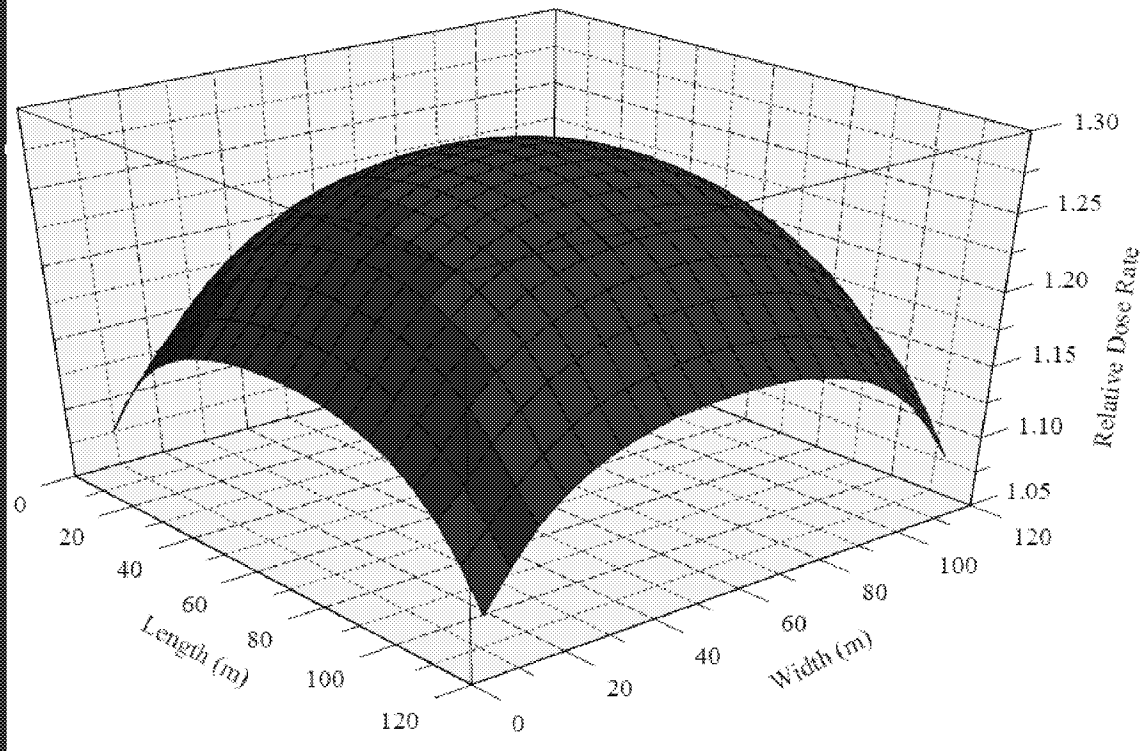


Fig. 3. Photon dose rate inside large room (400 x 400 x40 ft) for a 100 keV source.

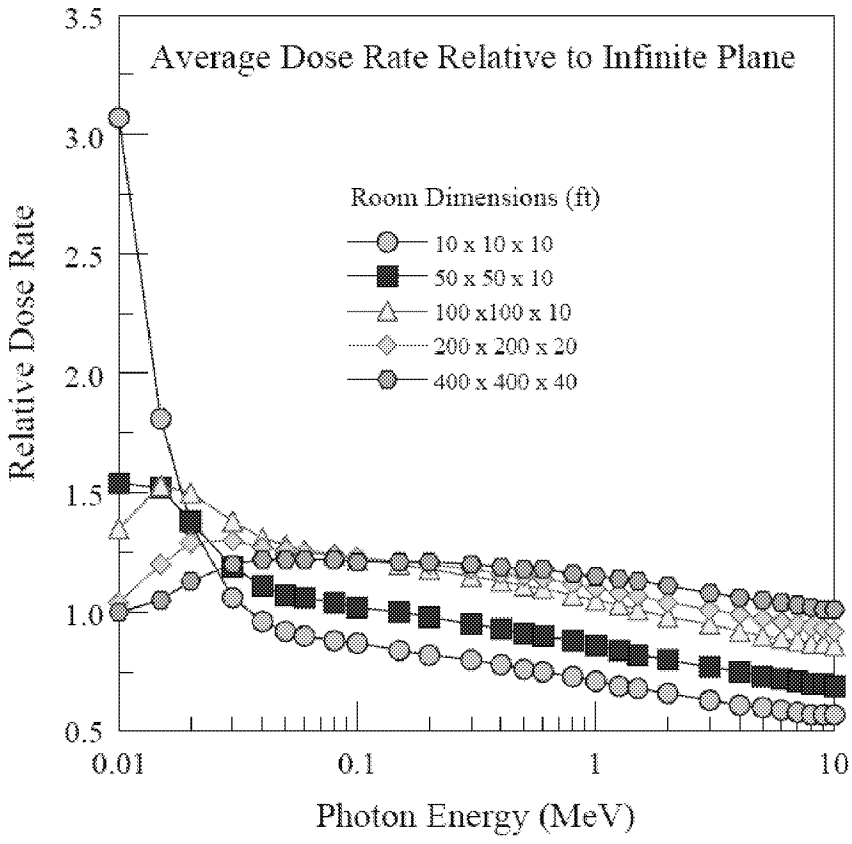


Fig. 5. Average relative photon dose rate for various size rooms.

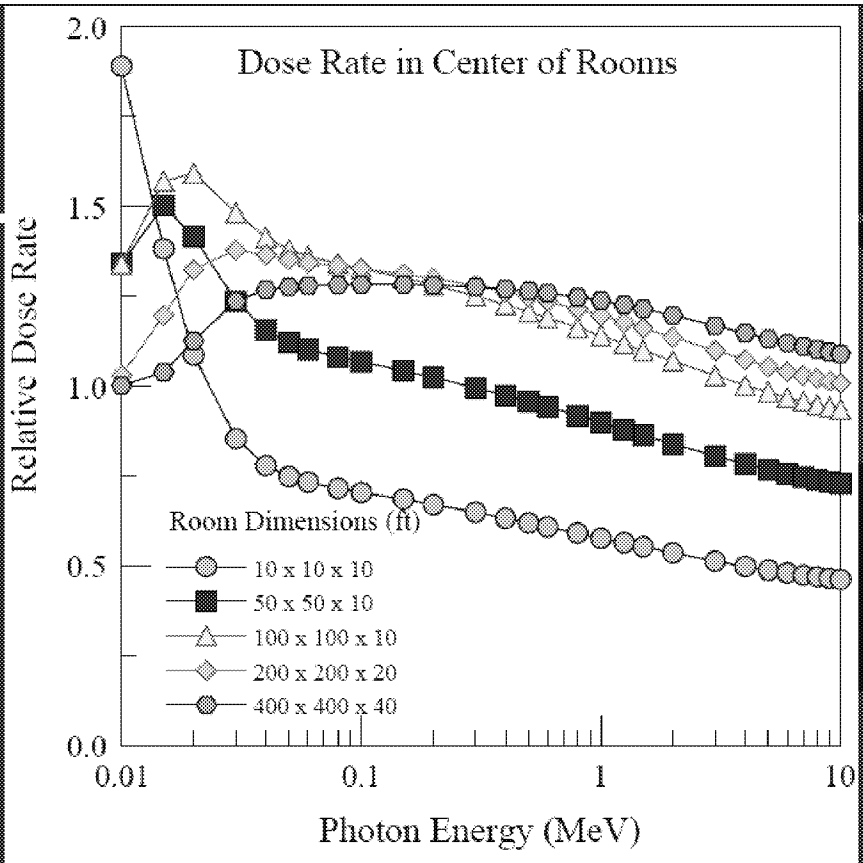


Fig. 6. Relative dose rate in center of rooms of various size.

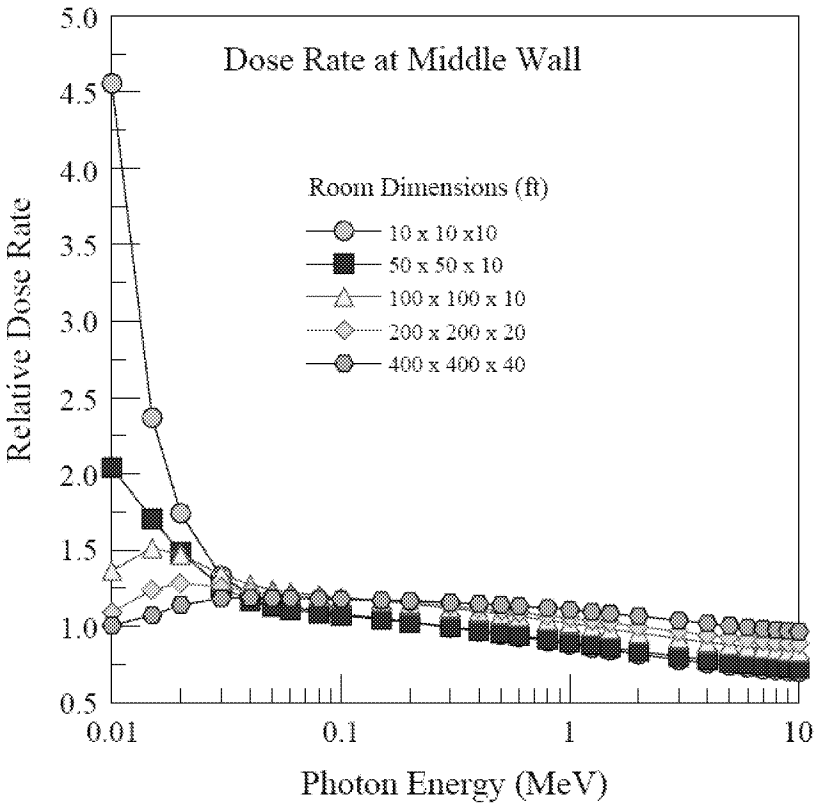


Fig. 7. Relative dose rate at middle of wall location in rooms of various size.

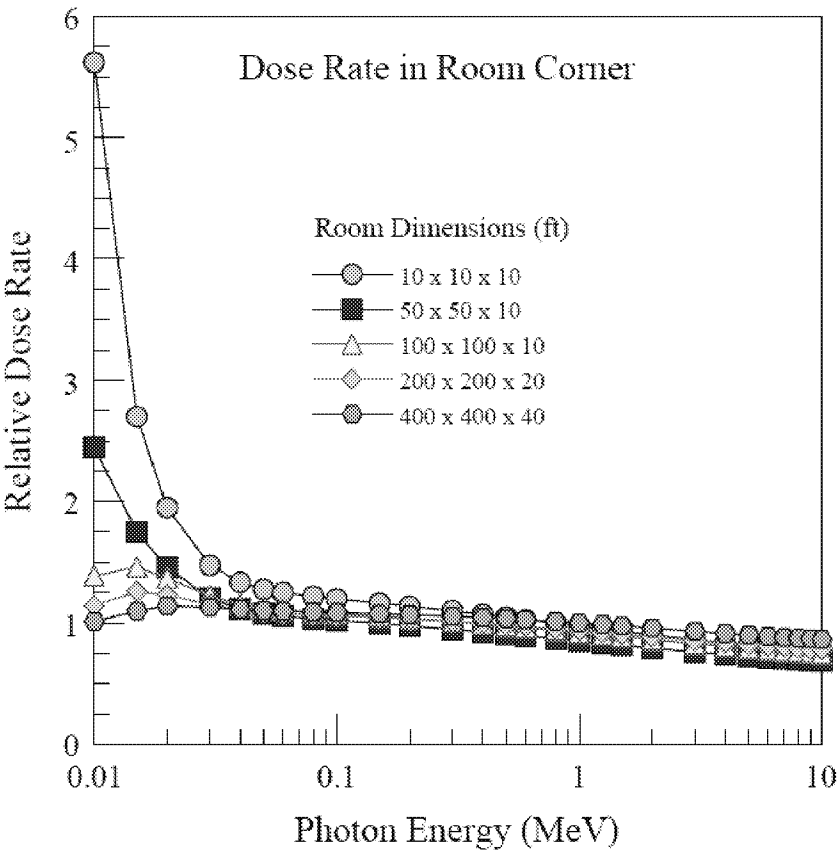


Fig. 8. Relative dose rate in the corner of rooms of various sizes.

BRPG/BDCC Recommendations

- Defaults toward most conservative combination (for both room size and location) for each radionuclide
- Recommend site-specifically pick room size.
- Usually pick average location unless site-specific information indicates receptor will spend most time in one location

Resident
3-D Direct External Exposure

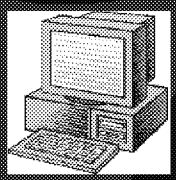
Soil Volume and Ground Plane External Exposure

$$BPRG_{3D\text{-}sv} = \frac{TR \times t_r \times \lambda}{SF_{ext\text{-}sv} \times F_{in} \times F_i \times F_{AM} \times F_{OFF\text{-}SET} \times F_{SURF} \times EF_r \times ED_r \times \left(\frac{1\ yr}{365\ d}\right) \times GSF \times \left(1 - e^{-\lambda t_r}\right) \times ET_r \times \left(\frac{1\ d}{24\ hr}\right)}$$

1.0E-6 TR (target cancer risk) unitless	1 F_{in} (fraction time spent indoor) unitless
1 F_i (fraction of time spent in compartment) unitless	1 F_{am} (area and materials factor) unitless
1 $F_{OFF\text{-}SET}$ (off-set factor) unitless	350 EF_r (exposure frequency) d/yr
30 ED_r (exposure duration - resident) years	1 GSF (gamma shielding factor) unitless
	Select a room position Select room position
24 ET_r (exposure time - resident) hr/day	
Select a room size Select room size (ft)	

Surfaces PRG (SPRG) Calculator

- Establish 1 x 10^{-6} risk based PRGs for radioactively contaminated ***outside*** hard surfaces (e.g., slabs, pavement, sidewalks, sides of buildings)
- Derived from rad PRG and BPRG calculators



EPA

Five of the criteria are known as the "balancing" criteria. These criteria are factors with which tradeoffs between alternatives are assessed so that the best option will be chosen, given site-specific data and conditions.

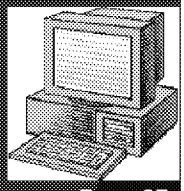
The criteria balance long-term effectiveness and permanence; reduction of toxicity, mobility, or volume; short-term effectiveness; implementability; and cost.

SPRG Exposure Scenarios

- SPRG includes 3 land use scenarios
  - Residential
  - Indoor Worker
  - Outdoor Worker
- 3 land uses include 3 exposure routes
  - Settled dust (street level)
  - **3-D Direct External (street level)**
    - **—Surface and Volumetric**
  - **2-D Direct External (slabs)**
    - **—Surface and Volumetric**

Surface Dose Cleanup Concentrations (SDCC) ARAR Dose Calculator

- SDCC Purpose: to establish DCCs for Outside Hard Surfaces for single dose limit ARARs (# mrem/yr)
- SDCC includes 3 land use scenarios (Residential, Indoor Worker, Outdoor Worker)
- 3 land uses include 3 exposure routes (Settled dust, Fixed Direct External 3-D, Fixed Direct External 2-D (slabs))
- Equations similar to those used for SPRG calculator, except dose conversion factors used instead of slope factors



EPA

Page-27

An approach similar to that taken for calculation of PRGs may also be used to calculate soil "compliance concentrations" based upon various methods of dose calculation.

A set of simple equations for target dose rate (e.g., either critical organ dose or single limits), radionuclide dose conversion factor (DCF), and intake/exposure parameters will be presented for use in calculating soil cleanup concentrations. These equations will be identical to those in the PRG for Radionuclides, except that the target dose rate (ARAR based) will be substituted for the target cancer risk (1 x 10-6), the period of exposure is one year to indicate year of peak dose, and a DCF will be used in place of the slope factor.

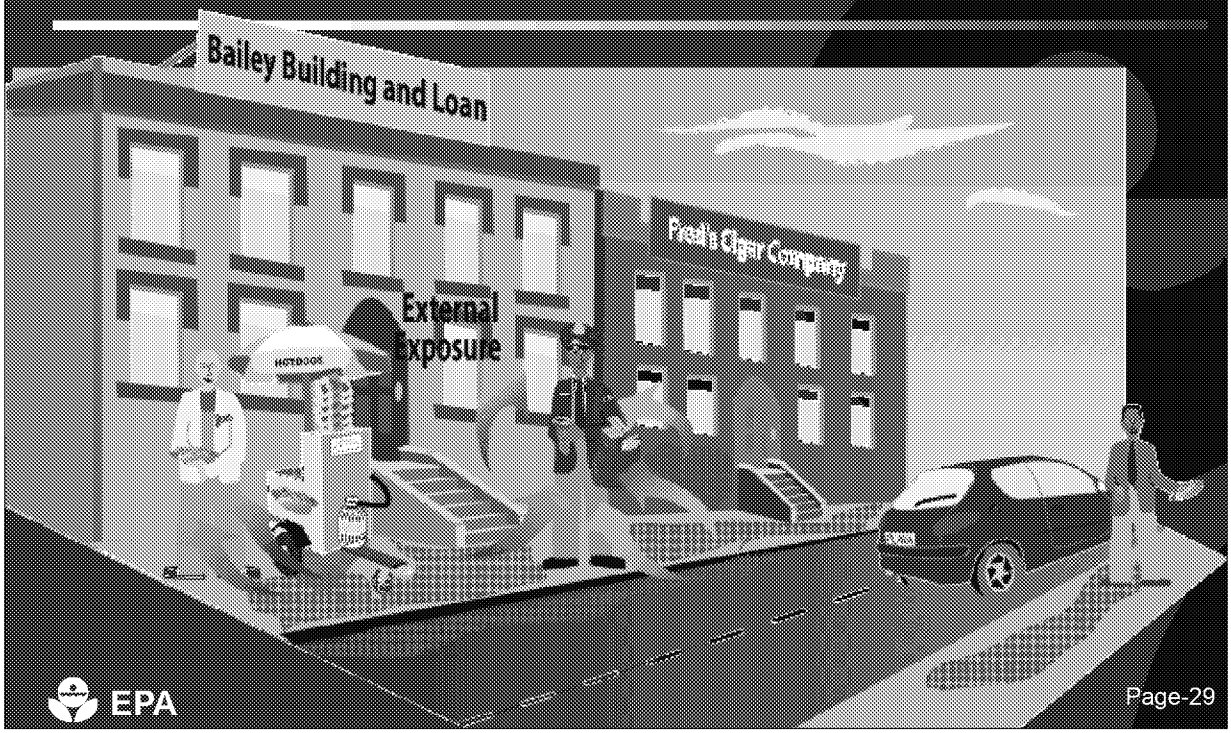
Please note that the target dose rate is generally a cleanup level when a dose standard is an ARAR (other than single dose limits greater than 15 mrem/yr such as NRC's 25/100 mrem/yr decommissioning rule), while the target risk number of 10-6 is a preliminary number.

Site decision-makers should choose the DCFs (ICRP 2, 30, or 60) required by the ARAR. Note that this calculator does not address ICRP 2. If DCFs are not specified within the regulation (for example, specifically required for compliance within the Code of Federal Regulations for a federal standard that is being complied with as an ARAR), then site decision-makers should generally use ICRP 2 DCFs for whole body and critical organ dose limits (e.g., 25/75/25 and 25/75 mrem/yr dose limits), and generally use ICRP 60 DCFs for single limit standards (e.g., 10 mrem/yr).

3-D External Residential Building Materials

EPA

3D-External Outside Workers Fixed Dust



EPA

SPRG/SDCC Positioning Factors: Building Heights

- 5 Building heights
  - 12 feet 6 inches
  - 30 feet
  - 59 feet
  - 150 feet
  - 200 feet

SPRG/SDCC Positioning Factors: Receptor Location

- 3 Receptor Locations for each of the 5 building heights
  - » Adjacent to Building
  - » Middle of Sidewalk
  - » Middle of Street

Table 2. Nuclide Dose Rate Coefficient Relative to Infinite Plane Coefficient.

	Building Height (ft)														
	12.5			30.0			59.0			150.0			200.0		
Nuclide	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)
H-3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Be-7	0.855	0.793	0.787	0.981	0.913	0.855	1.070	1.001	0.936	1.177	1.110	1.047	1.203	1.135	1.074
Be-10	0.938	0.865	0.853	1.070	0.989	0.919	1.153	1.072	0.992	1.238	1.158	1.081	1.254	1.174	1.098
C-11	0.851	0.790	0.784	0.977	0.909	0.852	1.066	0.998	0.933	1.174	1.107	1.045	1.200	1.132	1.072

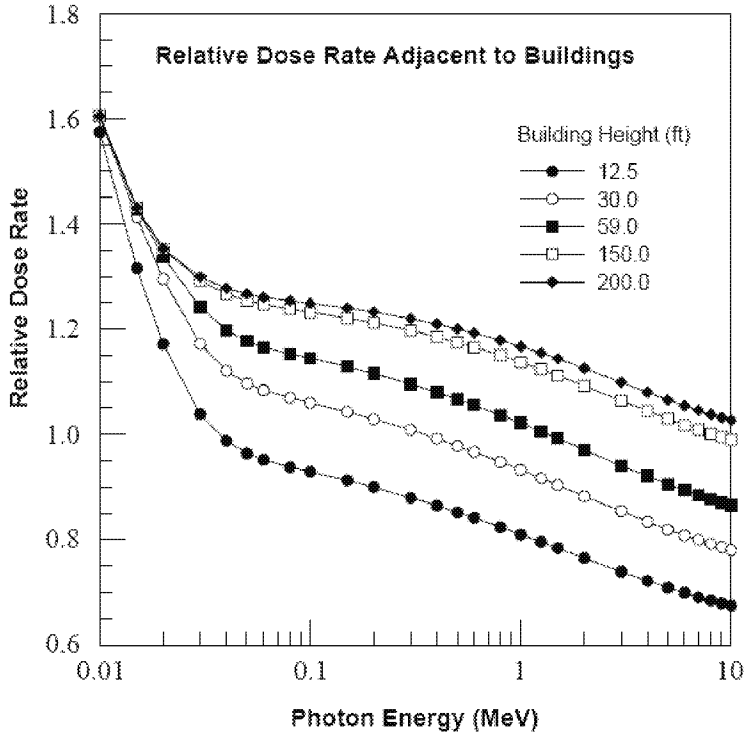


Fig. 1. Relative photon dose rate adjacent to buildings of various heights as a function of photon energy.

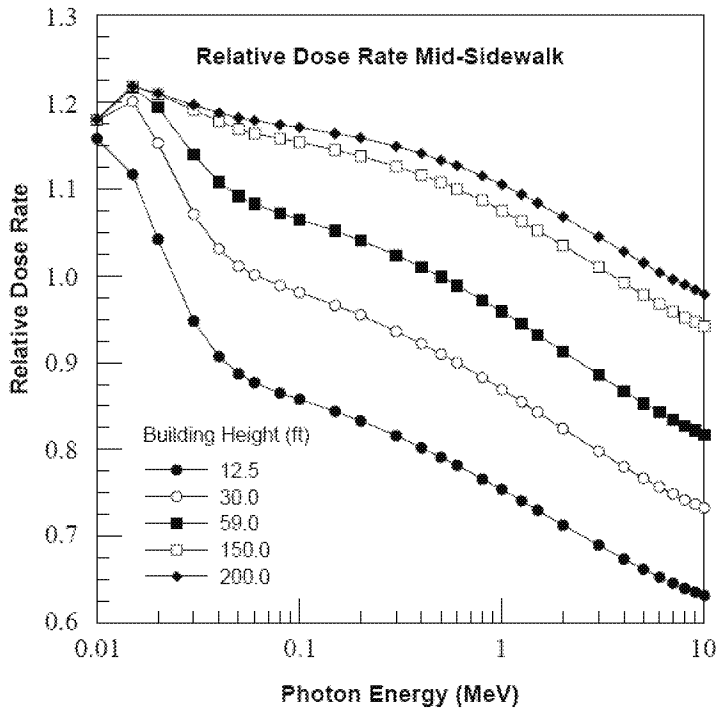


Fig. 2. Relative photon dose rate at the middle of the sidewalk lined by buildings of various heights as a function of photon energy.

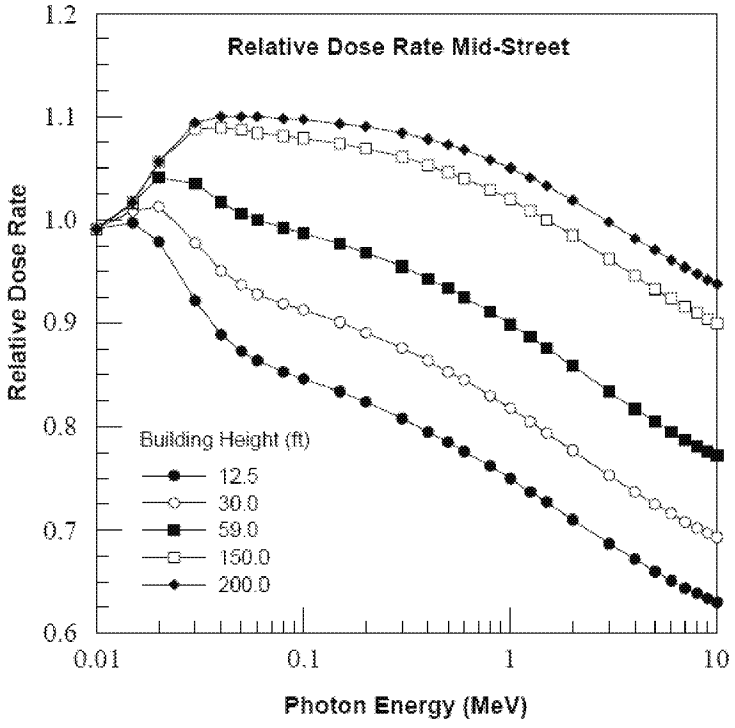


Fig. 3. Relative photon dose rate in middle of street lined with buildings of various heights as a function of photon energy.

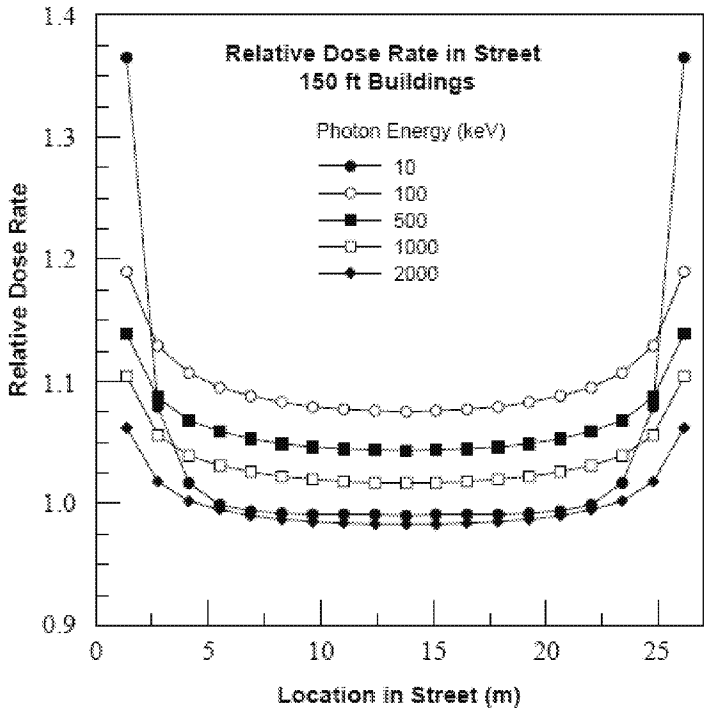


Fig. 4. Relative dose rate as a function of distance across street for selected photon energies. Street lined with buildings of height 150 ft.

SPRG/SDCC 3-D Recommendation

- Default to highest building height
- Alter based on building height of neighborhood, zoning

EPA

Residential
3-D Direct External Exposure

Soil Volume and Ground Plane External Exposure

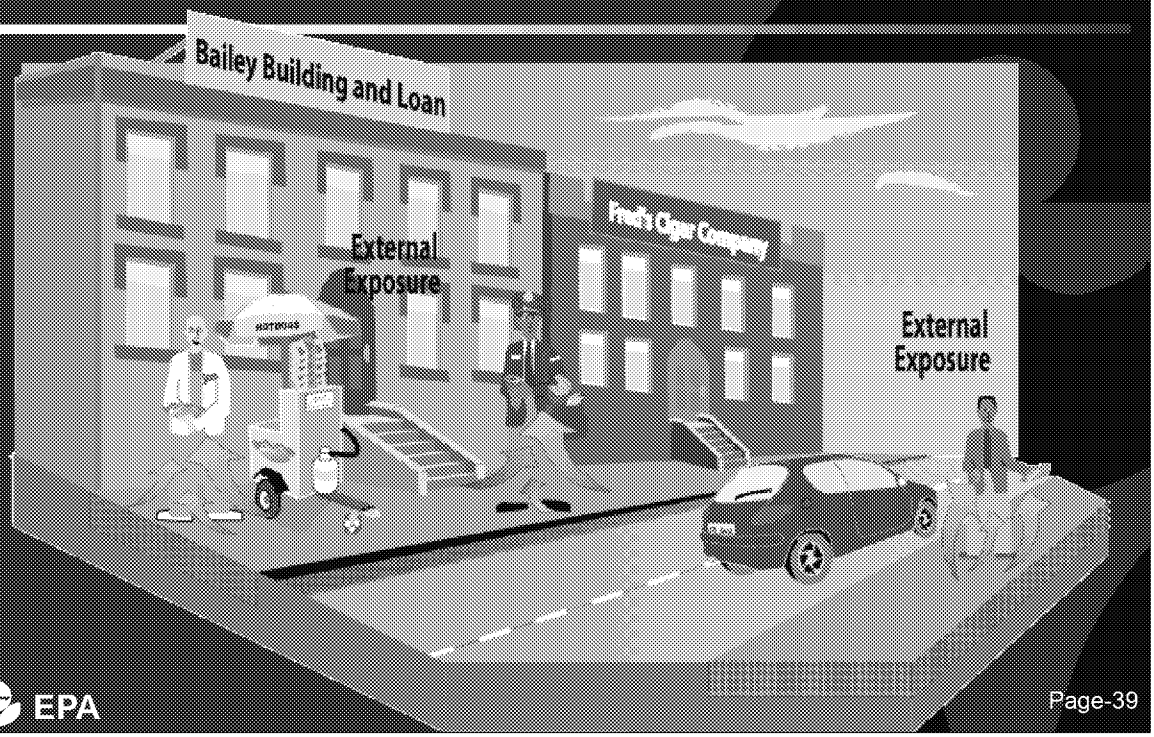
$$SPRG_{3\text{-}Dr\text{-}sv}\left(\frac{pCi}{g}\right)=\frac{TR\times t_r\,(years)\times\lambda\left(\frac{1}{years}\right)}{SF_{ext}\left[\left(\frac{risk}{year}\right)/\left(\frac{pCi}{g}\right)\right]\times F_{CD}\times F_{AM}\times F_{OFF\text{-}SET}\times EF_r\left(\frac{350\ days}{year}\right)\times ED_r\,(30\ years)\times\left(\frac{1\,day}{24\,hours}\right)\times\left(1-e^{-\lambda t_r}\right)\times \left[ET_{o,r}\left(\frac{1.752\ hours}{day}\right)\times GSF_o\,(1.0)+ET_{i,r}\left(\frac{16.4\ hours}{day}\right)\times GSF_i\,(0.4)\right]\times\left(\frac{1\,year}{365\,days}\right)\times F_{SURF}}$$

1.0E-6	TR (target cancer risk) unitless	30	t_r (time-resident) yr
1	F_{CD} (depth and cover function) unitless	1	F_{AM} (area and material factor) unitless
1	$F_{OFF\text{-}SET}$ (off-set factor) unitless	350	EF_r (exposure frequency) d/yr
1.752	$ET_{o,r}$ (outdoor exposure time) hr/day	1	ACF (Area Correction Factor) unitless
0.4	GSF_i (indoor gamma shielding factor) unitless	1	GSF_o (outdoor gamma shielding factor) unitless
Select a building height (ft)	Select building height (ft)	16.4	$ET_{i,r}$ (indoor exposure time) hr/day
		Select a sidewalk/street position	Select sidewalk/street position

SPRG/SDCC Building Slabs

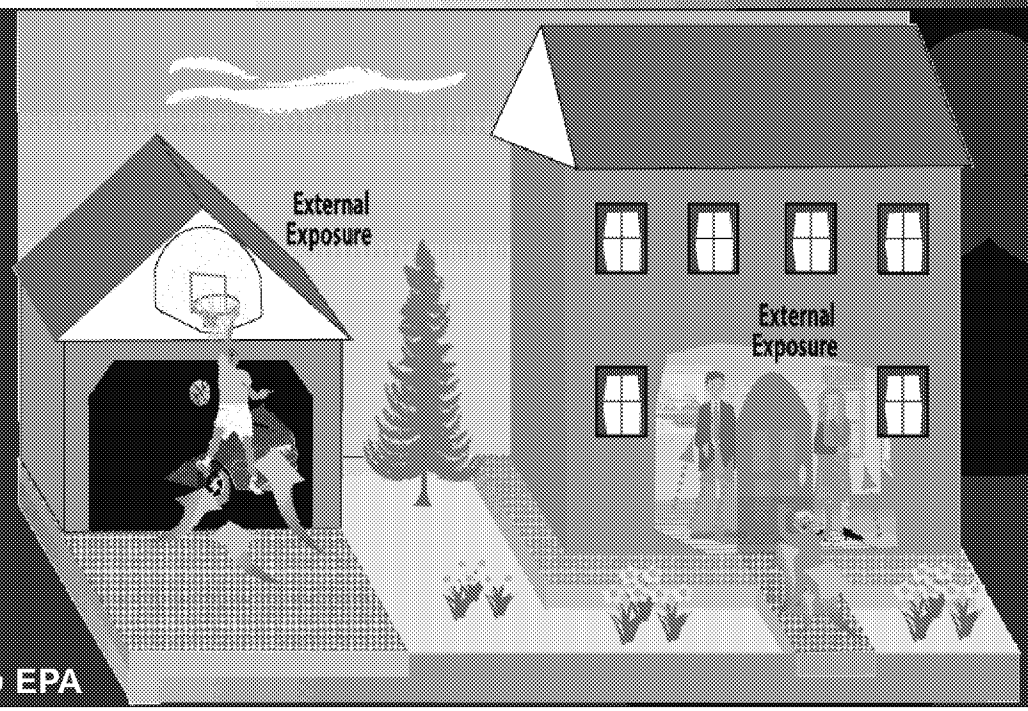
- Includes new ACF
- Same site sizes, but different ACF for each size for over 800 radionuclides
- Added to PRG and DCC calculators

SPRG/SDCC 2-D External Outside Workers Contaminated Building Slabs



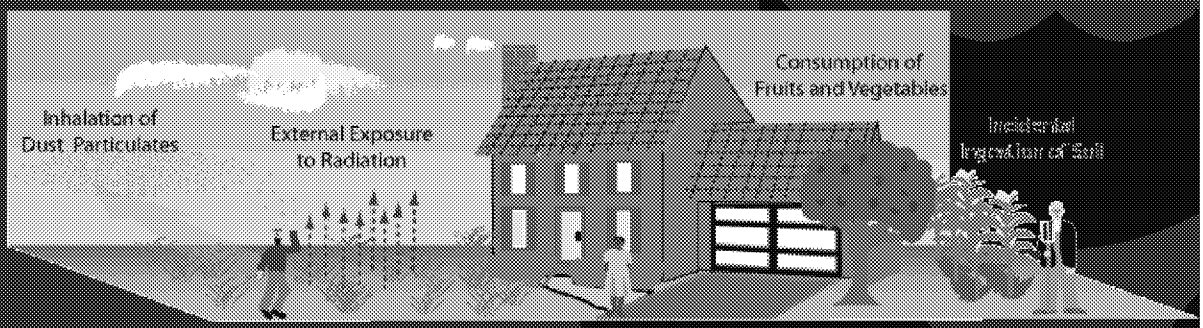
EPA

SPRG/SDCC 2D External Residential Fixed Dust



EPA

PRG/DCC Residential Soil



EPA

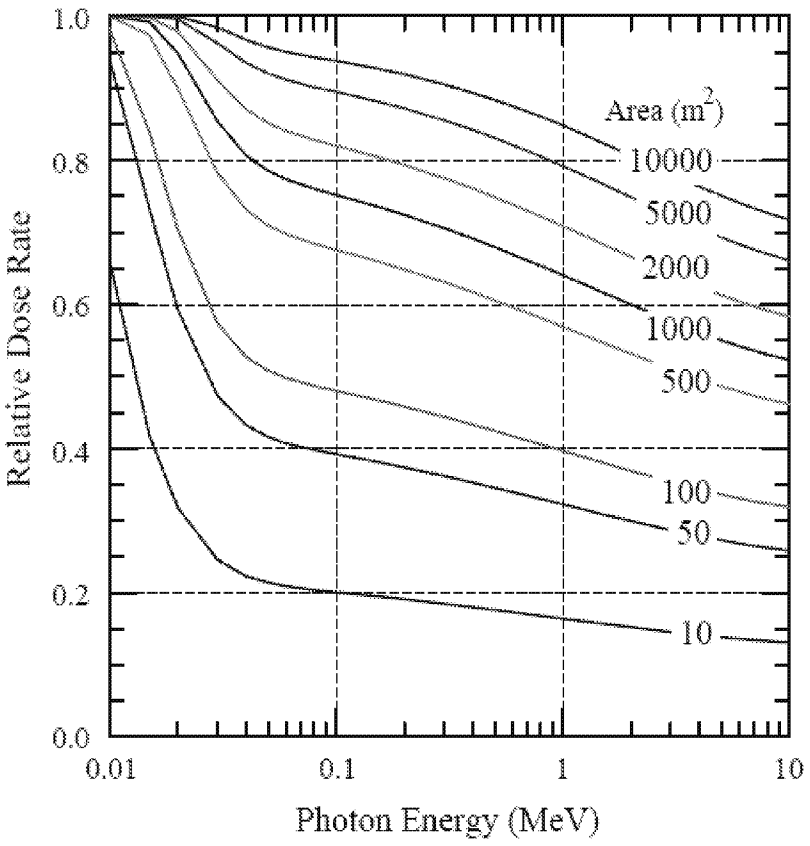


Fig. 1. Relative photon dose rate at the center of slabs of various sizes.

SPRG/SDCC 2-D Recommendation

- Default to largest slab size (10,000 m2)
- Alter based on size of actual slabs
- Recommendation same for PRG/DCC for site size

EPA

Residential
2-D Direct External Exposure

Soil Volume and Ground Plane External Exposure

$$SPRG_{2\text{-}Dr\text{-}sv}\left(\frac{pCi}{g}\right)=\frac{TR\times t_r\,(years)\times\lambda\left(\frac{1}{years}\right)}{SF_{ext}\left[\left(\frac{risk}{year}\right)\Big/\left(\frac{pCi}{g}\right)\right]\times F_{CD}\times F_{AM}\times F_{OFF\text{-}SET}\times EF_r\left(\frac{350\ days}{year}\right)\times ED_r\,(30\ years)\times\left(\frac{1\,day}{24\,hours}\right)\times ACF\times\left(1-e^{-\lambda t_r}\right)\times\left[ET_{o,r}\left(\frac{1.752\ hours}{day}\right)\times GSF_o\,(1.0)+ET_{i,r}\left(\frac{16.4\ hours}{day}\right)\times GSF_i\,(0.4)\right]\times\left(\frac{1\,year}{365\,days}\right)}$$

Select a slab size — Select Area Correction Factor for slab size

Resident Exposure to Soil

Ingestion, External, Inhalation, and Produce Exposure

Soil External Exposure

Soil Ingestion

Soil Inhalation

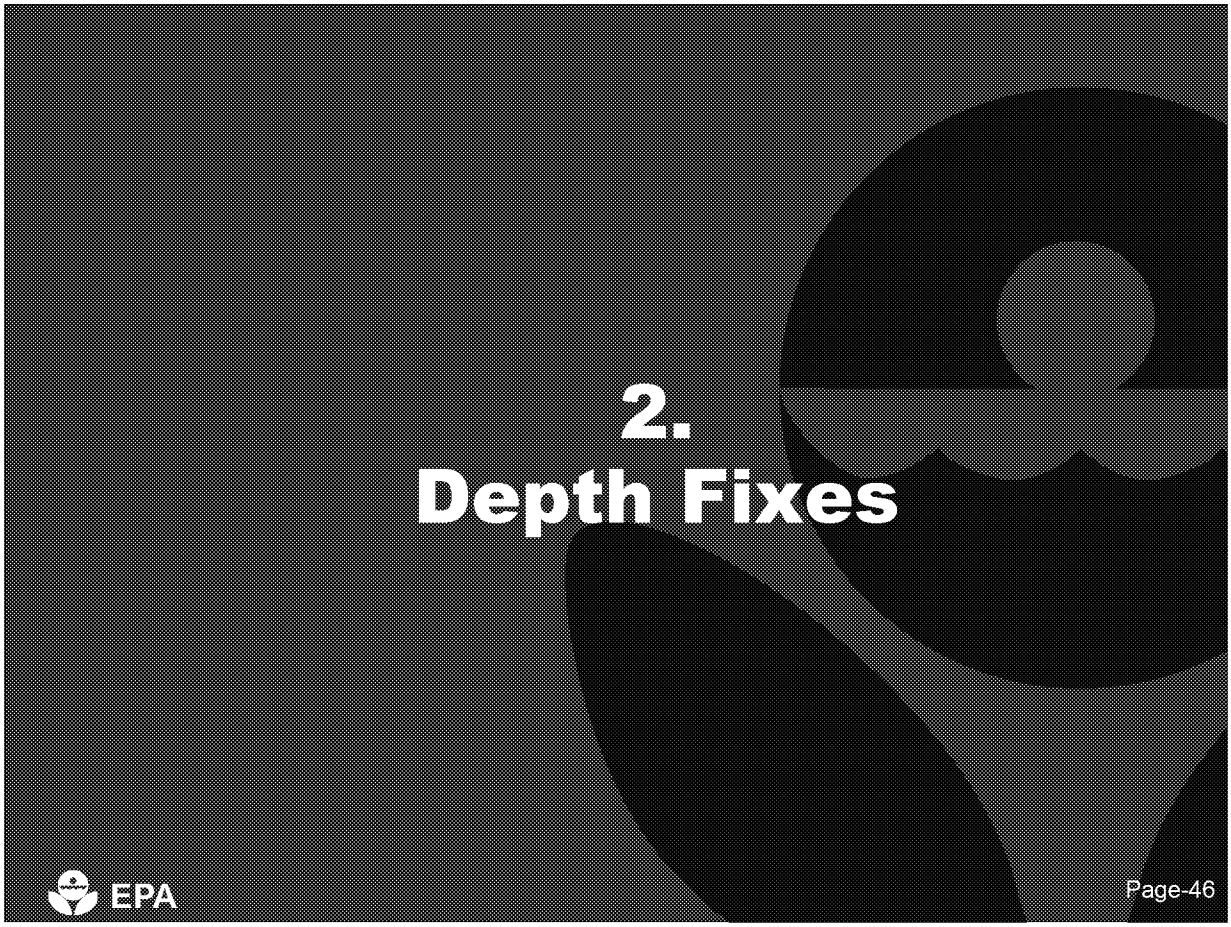
Soil Produce Exposure

Soil Total

Select a slab size — Select slab size for ACF

0.25 CPF_r (contaminated plant fraction)

7.40 $IFF_{r\text{-}adj}$ (age-adjusted fruit ingestion factor) mg-yr/kg-day


2.
Depth Fixes
EPA
Page-46

Old PRG and DCC - External Slope and Dose Conversion Factors

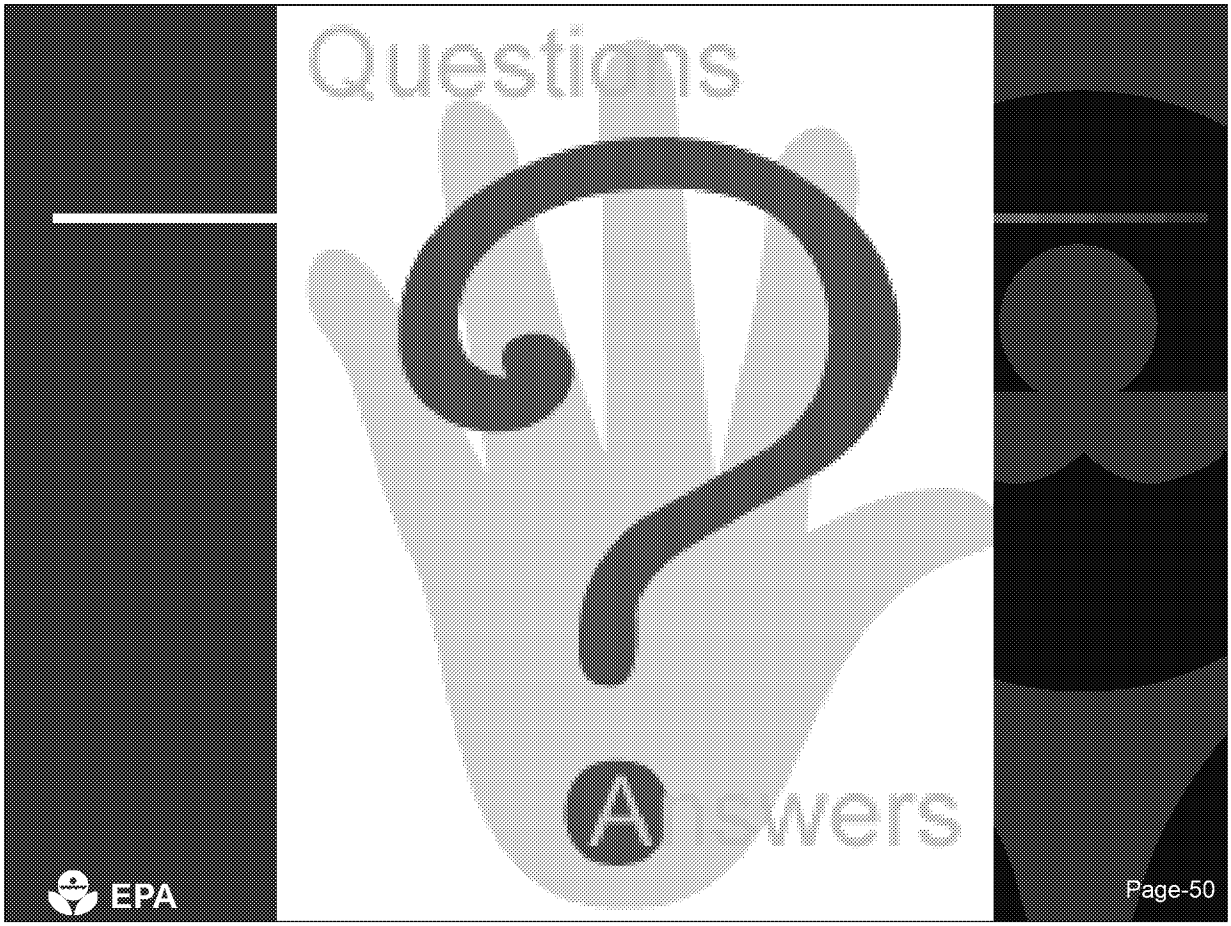
- PRG included 1 set of external (gamma) slope factors
  - » Infinite depth/infinite plane (traditional)
- DCC included 1 set of external dose conversion factors
  - » Infinite depth/infinite plane (traditional)

PRG, SPRG, BPRG – External (Gamma) Slope Factors

- PRG now includes 5 sets of external slope factors
  - » Infinite depth/infinite plane (HEAST)
  - » Ground plane/infinite plane (BPRG)
  - » 1 centimeter/infinite plane (SPRG)
  - » 5 centimeter/infinite plane (SPRG)
  - » 15 centimeter/infinite plane (SPRG)
  - » Submersion in air (BPRG)
    - —Ground plane and centimeter slope factors adjusted from ICRP 72 DCFs in FGR-13

DCC, BDCC, SDCC – External (Gamma) Dose Conversion Factors

- DCC now includes 5 sets of external dose conversion factors
  - » Infinite depth/infinite plane (FGR-13)
  - » Ground plane/infinite plane (BDCC)
  - » 1 centimeter/infinite plane (SDCC)
  - » 5 centimeter/infinite plane (SDCC)
  - » 15 centimeter/infinite plane (SDCC)
  - » Submersion in air (BDCC)


Questions
?
Answers
EPA
Page-50